



GT2003-39026 Microturbine Developments at Bowman Power Systems – Recuperator Evaluation

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Presentation Summary

1. Alternative recuperator – the motivation
 2. Alternative recuperators – the options
 3. Recuperator Integration
 4. BPS Historical Perspective
 5. Engine Control Developments
 6. Performance Mapping of Baseline Recuperator
 7. Materials Testing
 8. Evaluation of Alternative Recuperator Options
- Conclusions & Summary



Recuperator Programme

Background to Programme

- Initiated as part of the drive for cost reduction
- Subsequently accelerated due to withdrawal of Solar Turbines from the recuperator market.
- At least six potential alternatives are being evaluated (performance, cost and durability).
- Alternative sources are targeted to be provisionally validated by August 2003.



The early years

- Limited alternatives in 1994
- BPS first evaluated aerospace plate and fin units
- Initial Solar units very expensive
- Very limited alternative suppliers as microturbine product was in it's infancy



Now - 2003

- At least 8 possible alternatives for Microturbines (data sources identified)
 - ACTE (suppliers literature)
 - Bosal
 - Wilson Turbo Power Inc (www.w-tp.com)
 - IRPS (www.irpowerworks.com, US 6,427,764)
 - Proe 90 (www.proepowersystems.com, ref patent US 6,390, 185)
 - RR (paper 99-GT-369)
 - RSAB (GT-2002-30402)
 - Sumitomo (suppliers sales literature)
 - Toyo (suppliers sales literature)
 - Solar licensee?



Brief Comparison

Manufacturer	Construction	Architecture	Material	Production Status
ACTE	Primary surface	Annular – continuous wound	SS347	Prototype – good tooling
Bosal	Early presentations suggested “plate and fin”	Annular - early presentations suggested involutes	?	Prototype
DGWT	Rotary regenerator	Annular ceramic core	Ceramic	Prototype
IRPS	Plate and fin	“Box”	SS.347	Production
Proe 90	Primary Surface	Multiple concentric tube	SS.347	Prototype?
RR	Hybrid primary surface/plate and fin	Annular – continuous wound	SS.347	Prototype
RSAB	Primary surface	“Box”	SS	Prototype
Solar	Primary surface	“Box”	SS.347	Ceased production
Sumitomo	Plate and fin	“Box”	?	Production
Toyo	Plate and fin	“Box”	?	Production



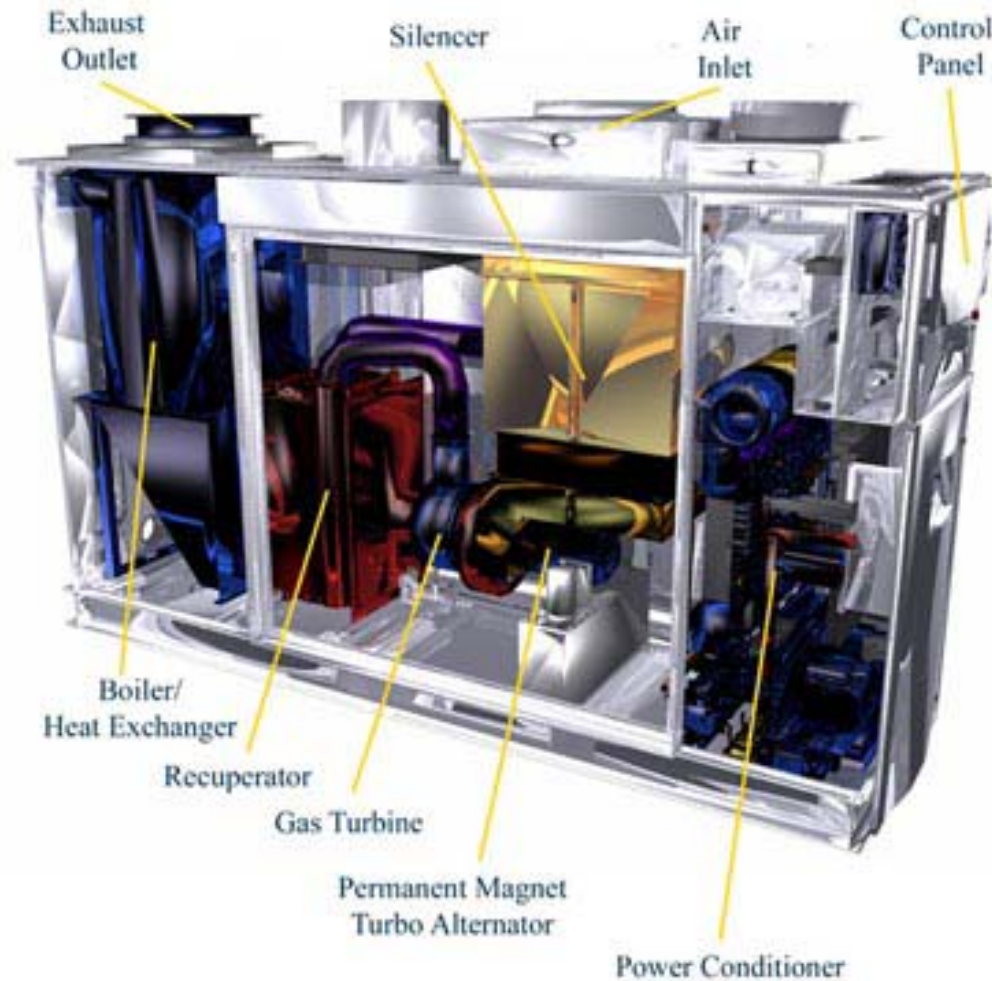
- 1997 Plate and fin recuperator evaluation
- Cross flow
- Low effectiveness (circa 75%)
- Very low life!



Wilson Turbo Power



- Regenerator core
- Interesting alternative?



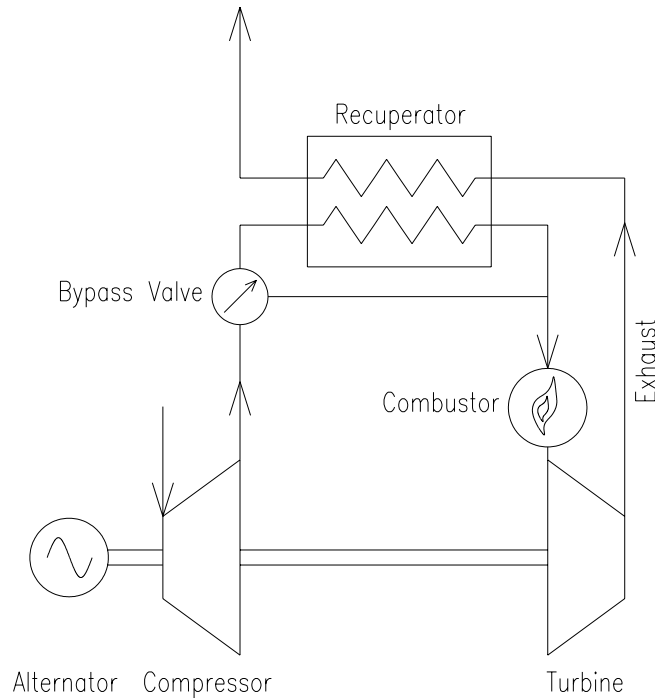


Package Integration

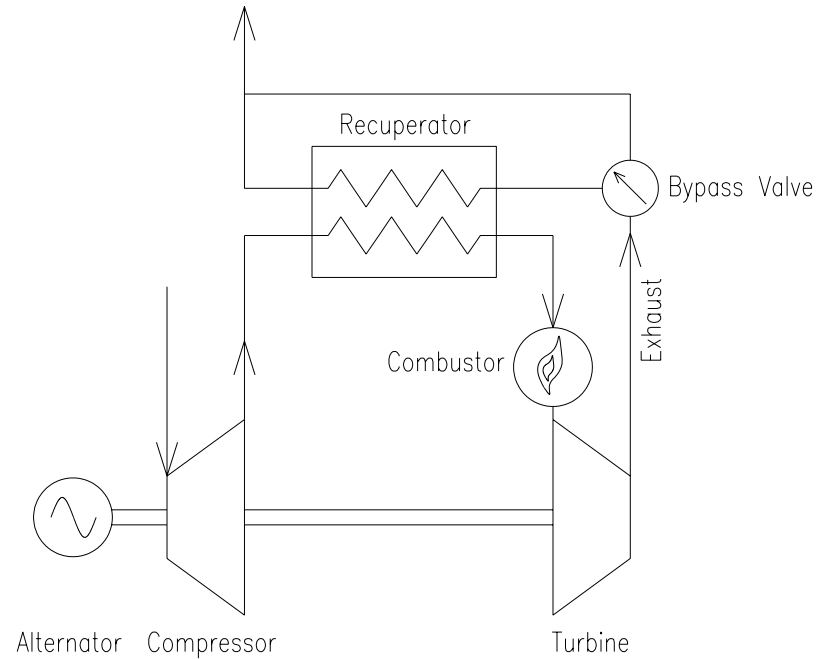
- The current package is optimised for the Solar recuperator
- Ideally the selected recuperator will not necessitate excessive changes to the package design
- The modularity of the package is attractive, helped by horizontal exhaust gas flow path
- Package width, height etc may be effected by recuperator – width limited to circa 750mm
- Overall installed cost a big factor
- Maintenance not to be inhibited/reduced by recuperator choice
- Larger engines with larger recuperator sizes (diameters on annular configurations) may effect packaging philosophy – these will have to be reviewed – thus <250kW engines may use recuperator supplier A and >250kW engines may use supplier B



Recuperator Bypass Options



Cold Side Bypass



Hot Side Bypass

Cold Side Bypass

- Recuperator matrix are exposed to high temperatures during bypass
- Simple integration for box recuperator
- Self cleaning by soaking at temperature is possible

Hot Side Bypass

- Recuperator matrix are exposed to low temperatures during bypass
- Simple integration for annular recuperator
- Soft start for recuperator is possible



Impact on Microturbine Performance

- 1% increase effectiveness = 0.3% increase in electrical efficiency
- 1% increase total dp/p = 1.8% reduction in power
- 1% increase total dp/p = 0.3% reduction in electrical efficiency



Historical Perspective

- BPS/EES combined experience with Solar recuperators circa 100,000 hrs
- Also used by Turbec, Sweden in box configuration
- Licensed by Capstone, USA in annular configuration
- BPS long life units circa 7,500 hrs and 500 start cycles
- Circa 130 units in operation
- Solar withdrew from market in 2001
- BPS made last buy sufficient for products to end Q1/04
- Solar recuperators not without their life issues associated with integration loads and thermal shocks

- Engine Control & Development
 - Solar limited thermal transient capability required implementation of soft starting to increase cyclic life
 - Less than optimum limitation, ideally recuperator selected will be capable of long life without soft starting techniques being employed

■ Test History

- Work originally conducted on test rig at the University of Sussex
- Single point performance validation undertaken on BPS test rig to qualify the test rig
- Sussex could not undertake cyclic testing
- Decided to continue all work at BPS



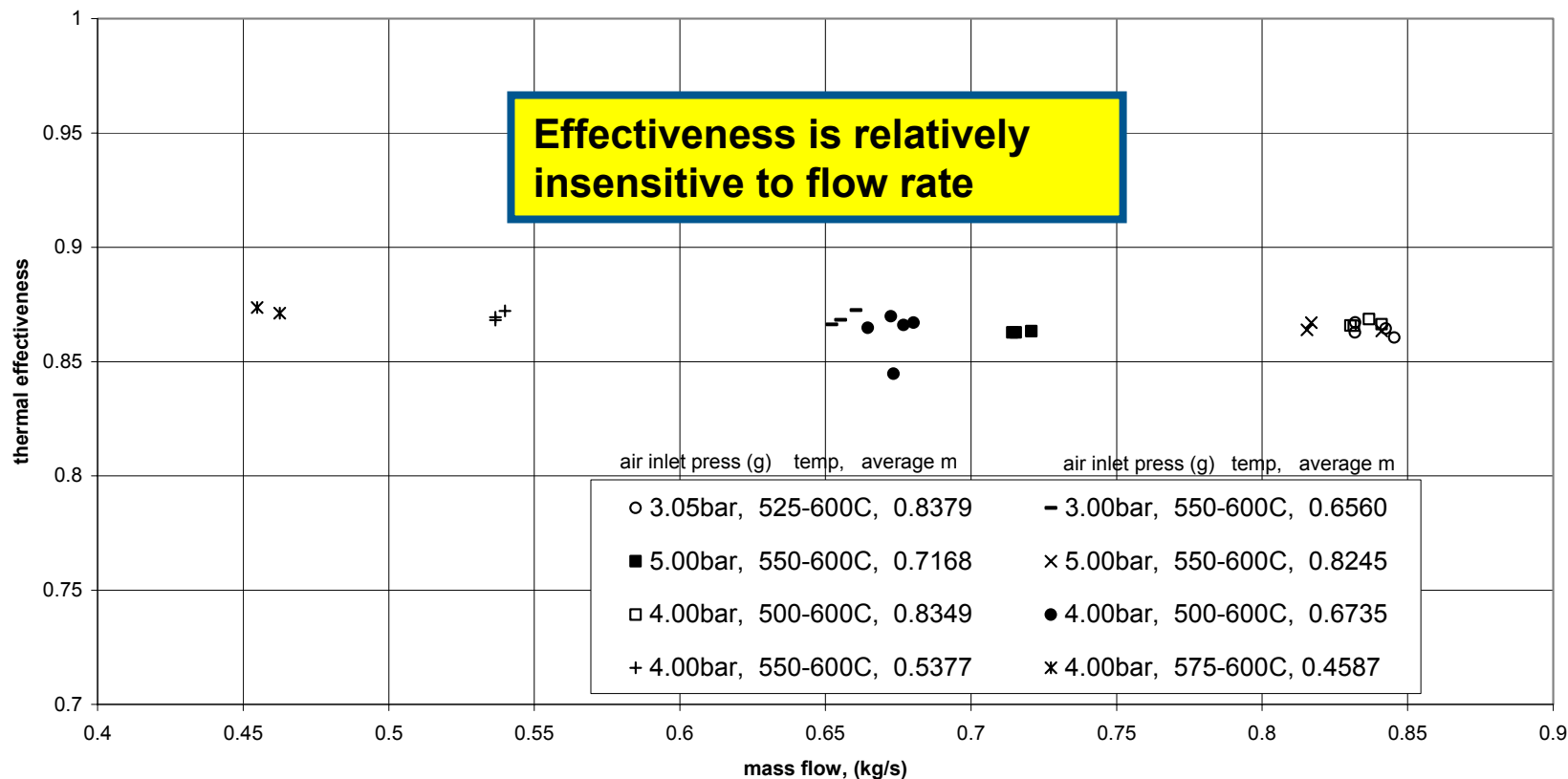


Fig 4. Solar Recuperator - Thermal effectiveness vs Mass Flow
Averaged Data Logger readings

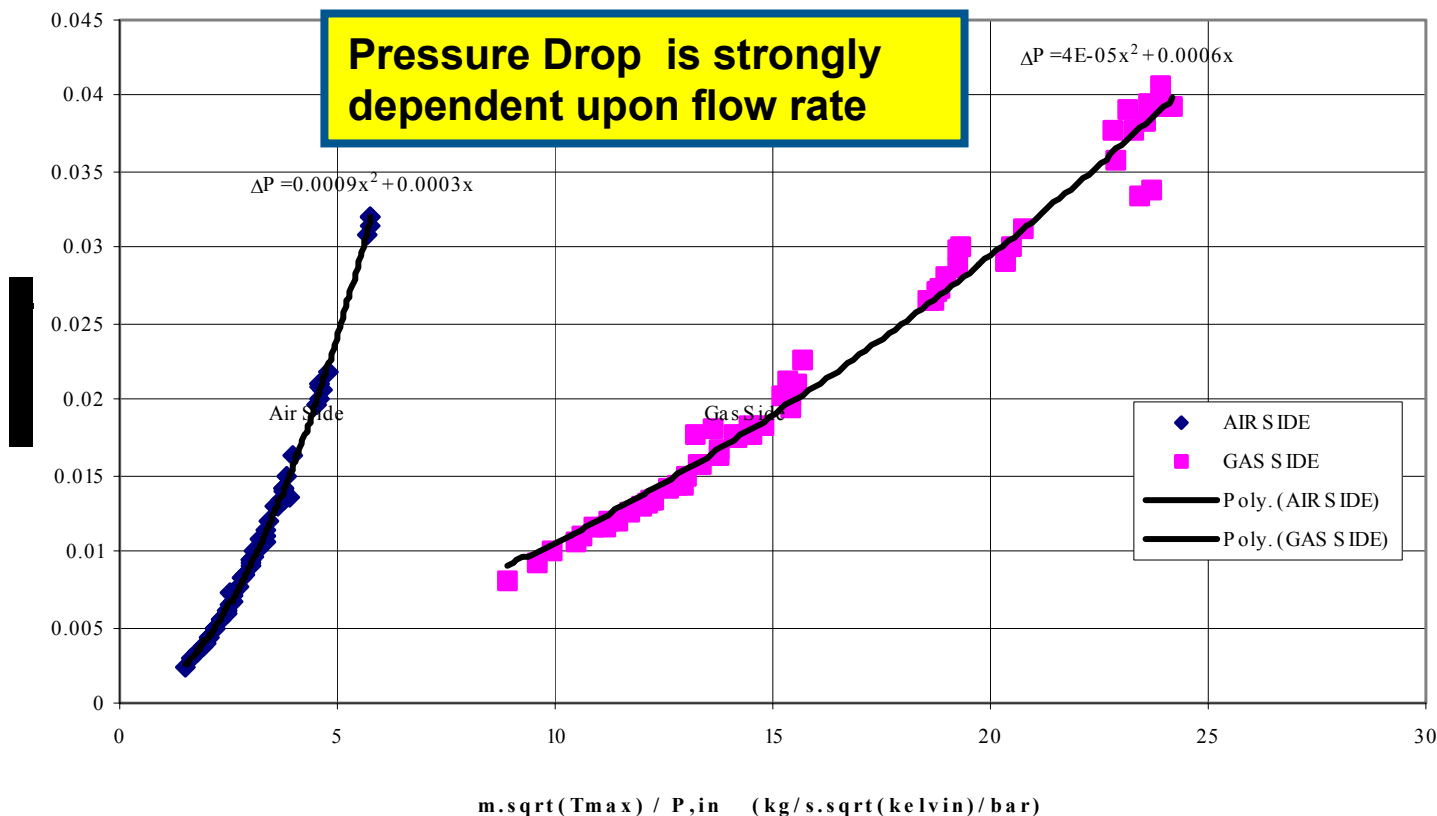


Fig 7 Solar Recuperator Pressure Drops - Air Side and Gas Side.
All Pressures (3 bar (g) to 5 bar(g)) and Temperatures (100°C to 600°C)

- ORNL (Oak Ridge) have raised concerns about corrosion of SS347 by water in flue gas
- BPS is following material test programmes at ORNL and NPL
- General temperature ratings:

	<u>deg C</u>
400 series ferritic alloys	600
300 series austenitic alloys	650
Advanced austenitic alloys	750
Nickel-based super alloys	800-850
NiCrAl or ODS FeCrAl	900

Satisfactory combination of the following attributes:

- Stress rupture
- Creep
- Fatigue
- Oxidation/corrosion
- Workability
- Joinability
- Cost

Objectives -

- To evaluate the life of the recuperators.
- To evaluate the % leak rate at the anticipated operating pressure.
- To confirm the manufacturers effectiveness and pressure drop claims.
- To evaluate the integration complexity.





Alternative Suppliers

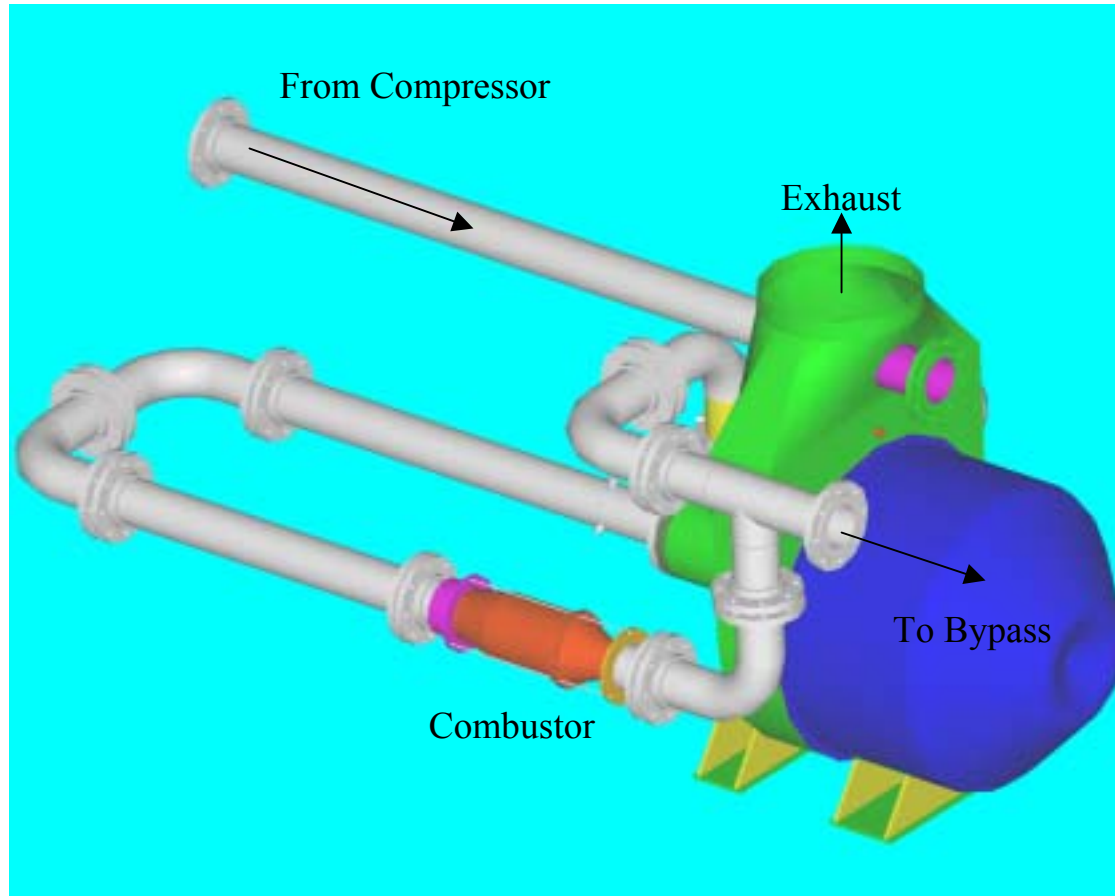
- In the last 3 years there have been many alternative suppliers publicising their products in the public domain, either through technical conferences or patent publications
 - Toyo – supplier to Honeywell/Allied Signal Parallon 75
 - Bosal – have presented papers at various conferences
 - RR – have presented papers at various conferences
 - RSAB - have presented papers at various conferences
 - IRPS – produced their own recuperator for their own engine and have won several supply contracts
 - EES – have patents on their own recuperator design
 - DGWT – regenerator
 - ACTE

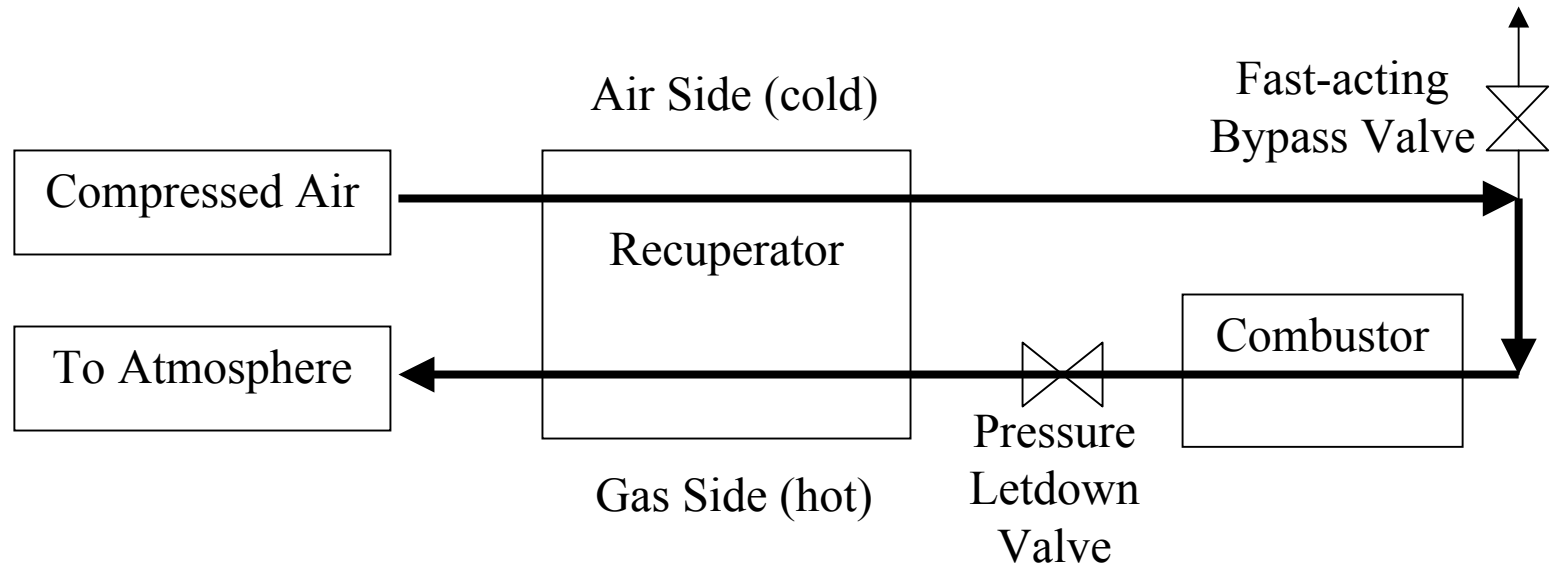
	<u>Desirable</u>	<u>Essential</u>
▪ Effectiveness	90%	85%
▪ Total pressure drop	<4%	<5%
▪ Hot gas inlet temperature	670°C	650°C
▪ Life (operating hours)	50,000	25,000
▪ Life (start/stop cycles)	10,000	5,000

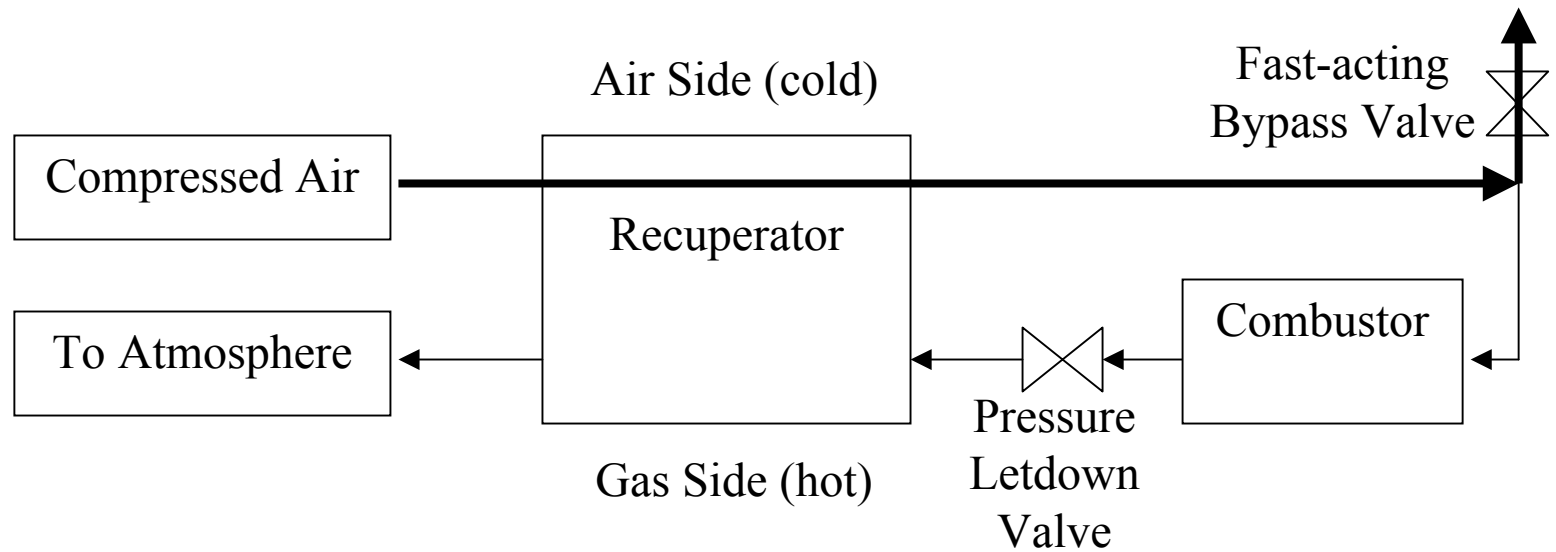
Recuperator Test Plan

1. **Initial leak test**
2. **Carry out an effectiveness and pressure drop check**
3. **Subject the recuperator to 1000 hot pressure cycles**
4. **Final leak test**
5. **End of test effectiveness and pressure drop check**

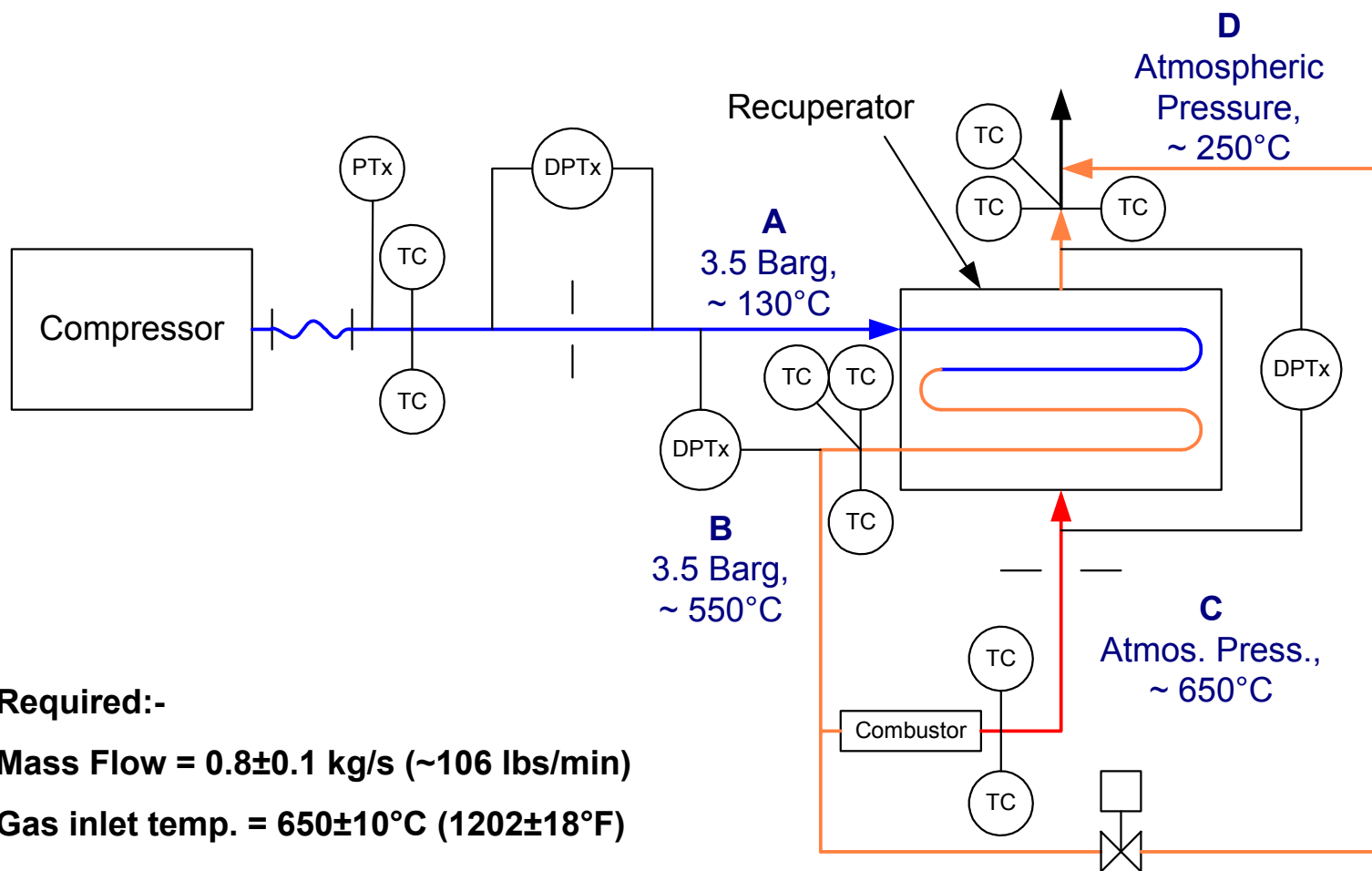








Test Rig – P. & I. Diagram

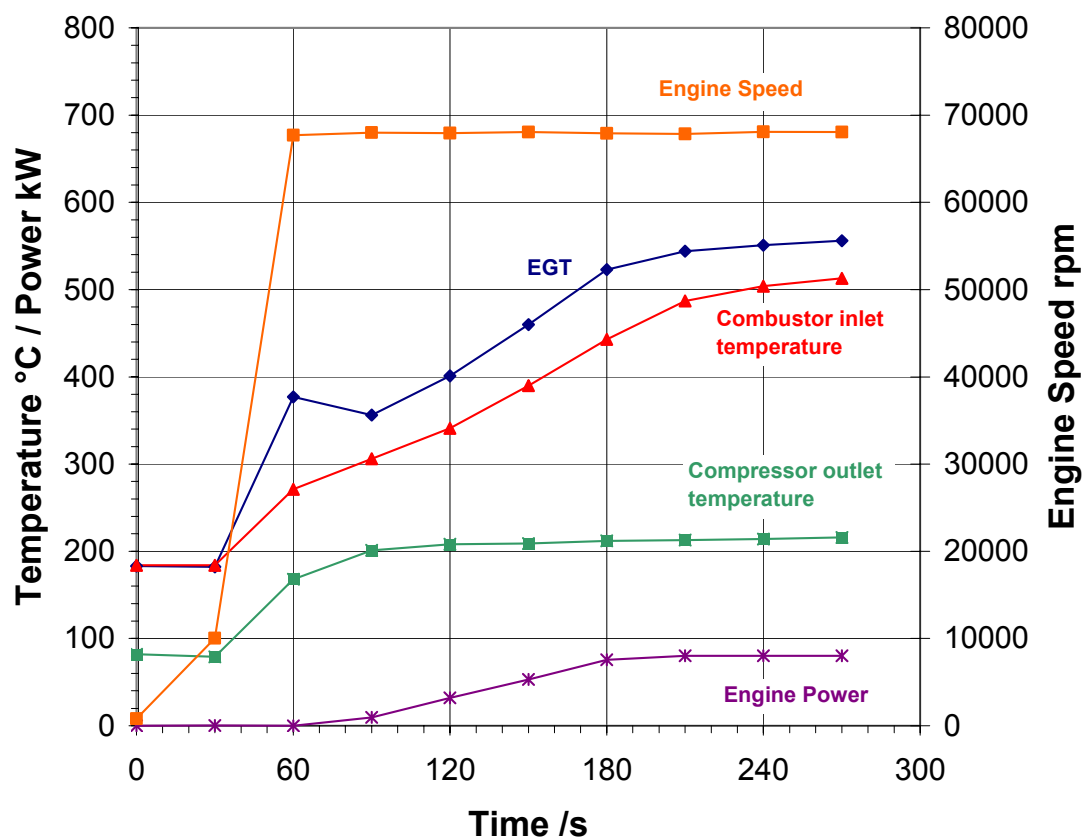


Required:-

Mass Flow = 0.8 ± 0.1 kg/s (~106 lbs/min)

Gas inlet temp. = $650 \pm 10^\circ\text{C}$ ($1202 \pm 18^\circ\text{F}$)

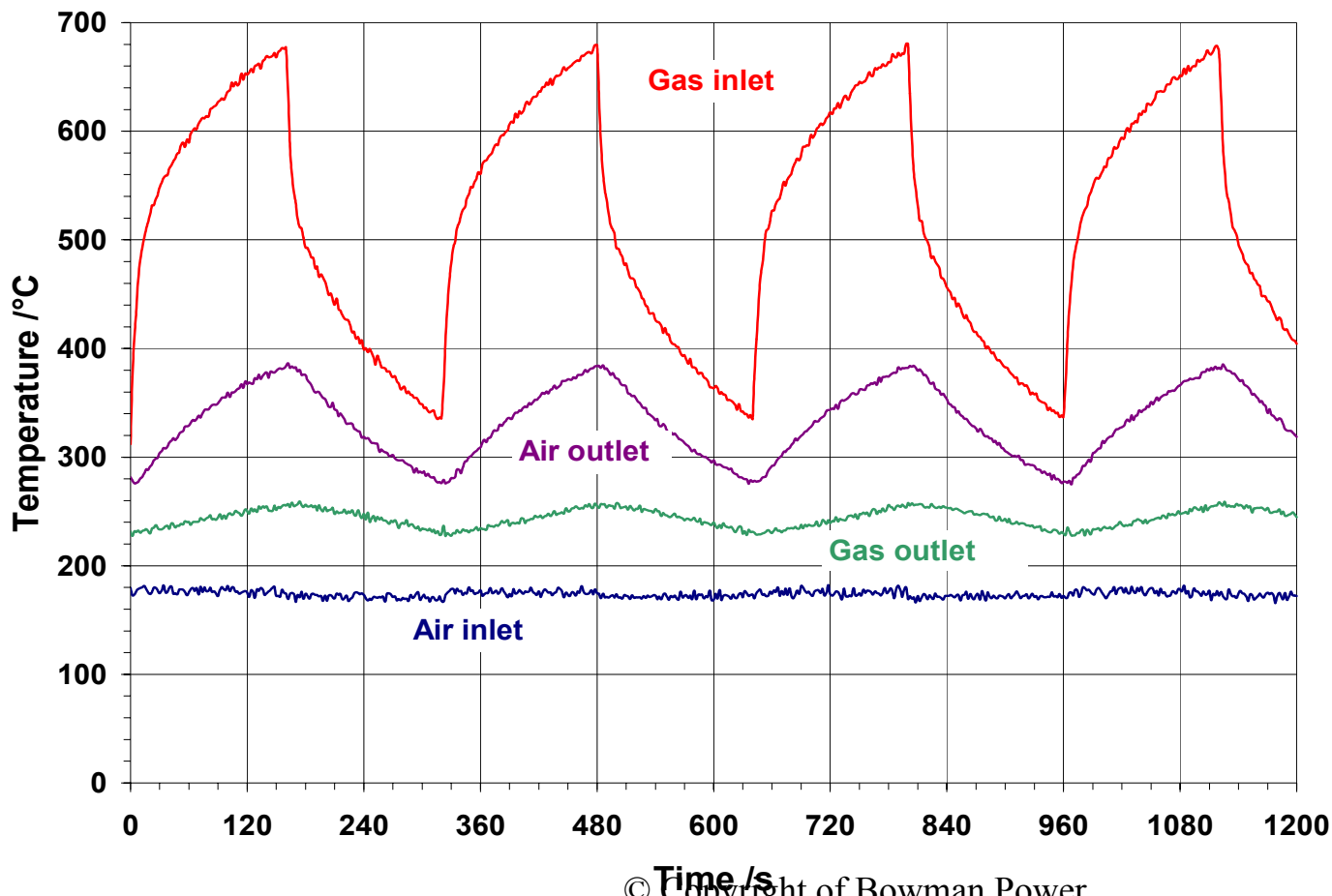
80kW Endurance Engine 080-078



Cycle time for a standard system ~ 4 minutes

However, time for the EGT to rise between 200°C (392°F) and 550°C (1022°F) is approx. 3 minutes.

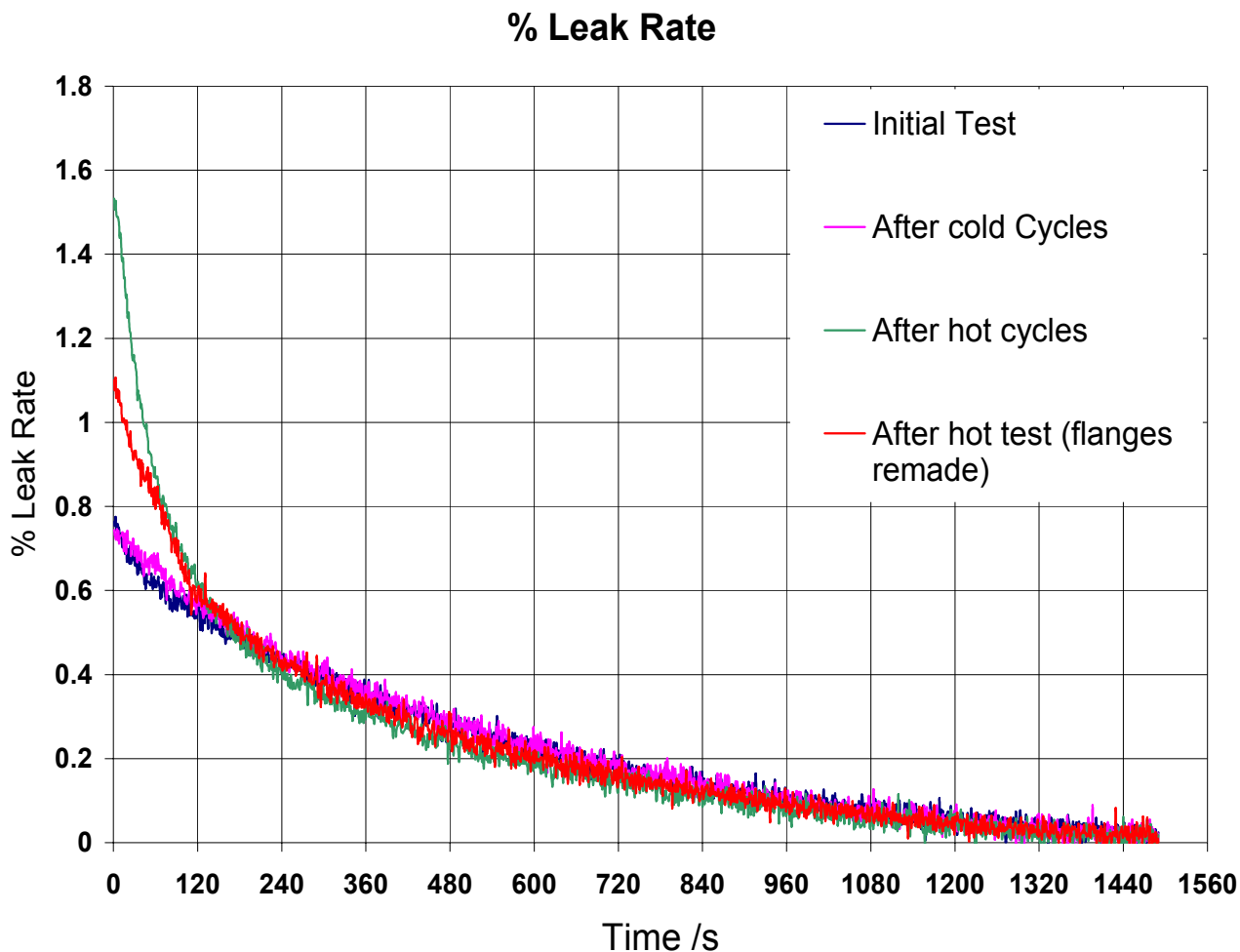
Hot Cycle Testing



Please note: - Due to a calibration error at this time the peak temperature value is reading 26°C (47°F) high.

Effectiveness	88%	
Pressure Drops:	<u>dp</u>	<u>dp/p</u>
Air Side	80 mbar	2%
<u>Gas Side</u>	7 mbar	<u>1%</u>
Total		3%
Mass Flow	0.7 kg/s	
Air Pressure	4.5 bara	
Inlet Temperatures:		
Gas Side	610°C	
Air Side	130°C	

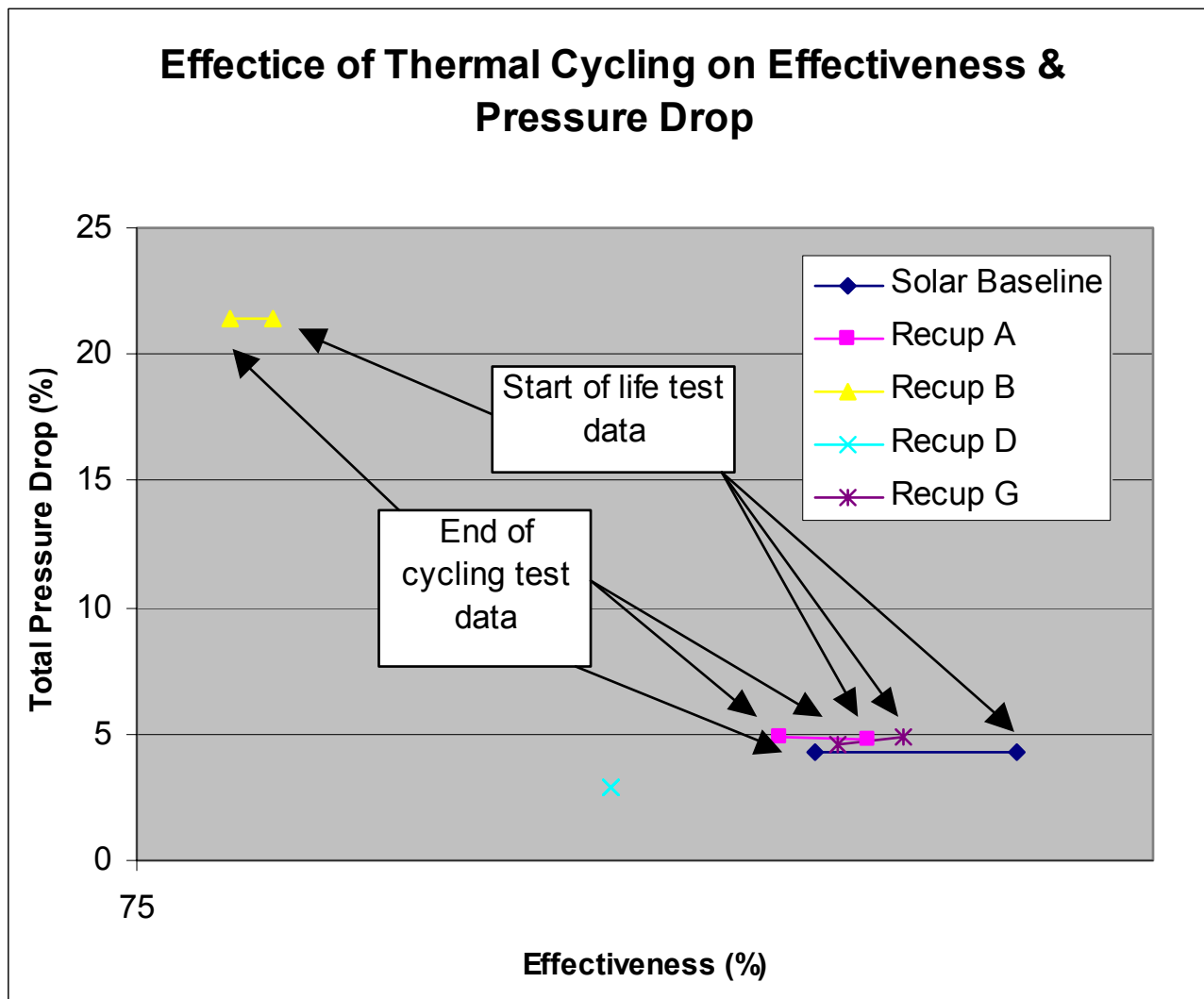






As Tested Performance

Feature	Solar (as tested at BPS)	Recup A	Recup B	Recup C	Recup D	Recup E	Recup F	Recup G
Pressure Drop – Air Side	2%	<	>>	Not yet tested	>	Not yet tested	Not yet tested	<
Pressure Drop – Gas Side	1%	>	>>	Not yet tested	<	Not yet tested	Not yet tested	>
Pressure Drop – Total	3%	>	>>	Not yet tested	<	Not yet tested	Not yet tested	>
Effectiveness	88%	<	<<	Not yet tested	<	Not yet tested	Not yet tested	<
Leakage - Start	0	<	>	Not yet tested	>	Not yet tested	Not yet tested	>
Leakage – End (1000 cycles)	0	<	>	Not yet tested	>	Not yet tested	Not yet tested	>

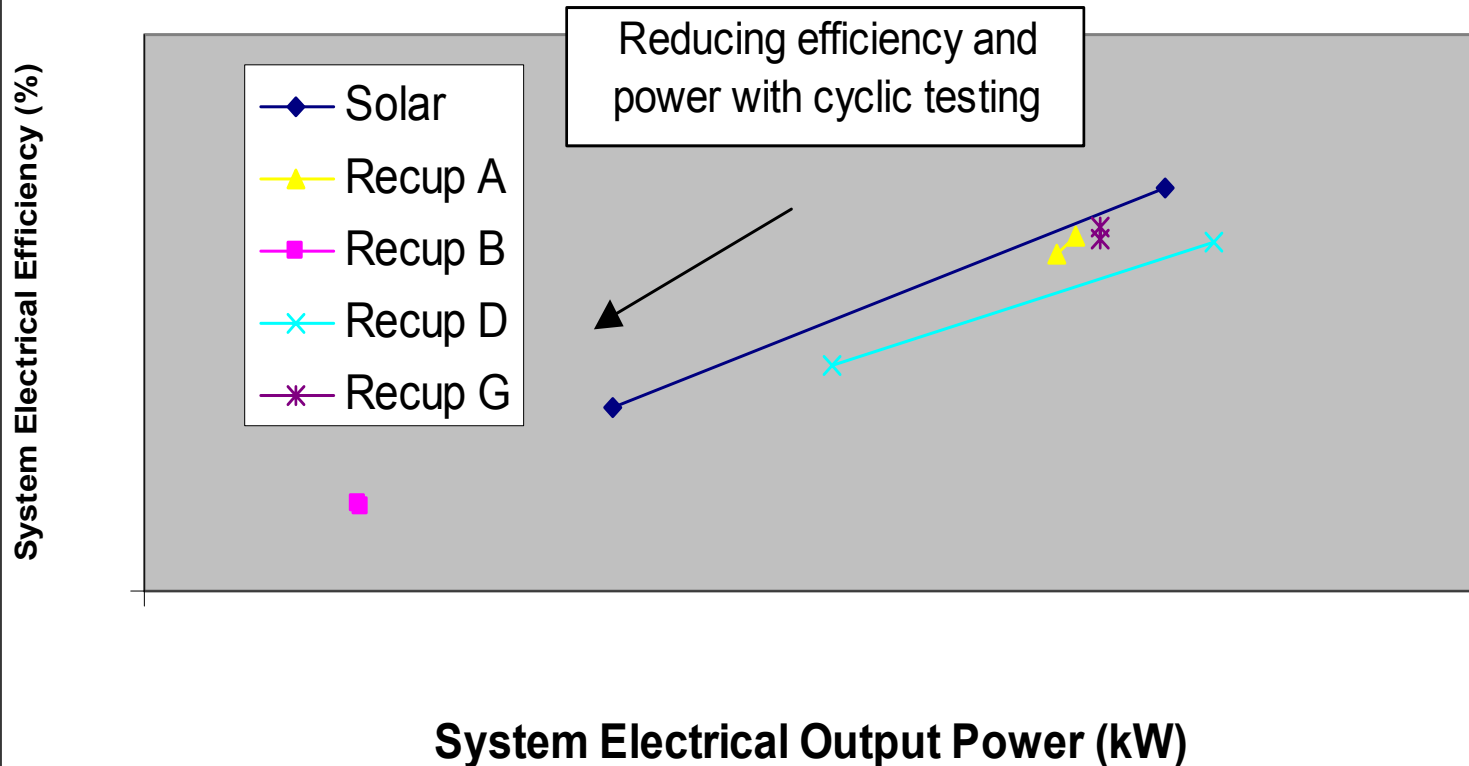


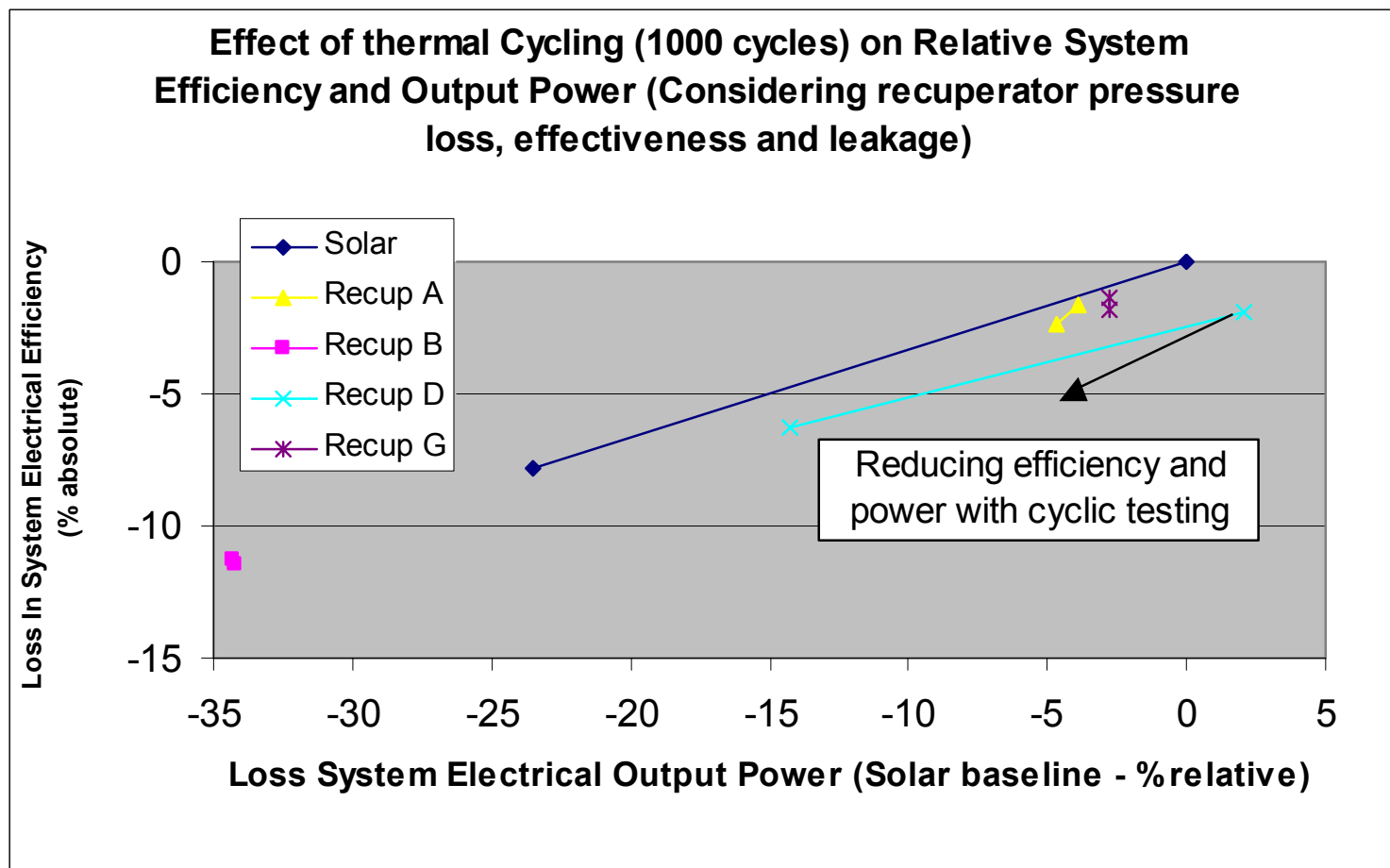


Explanation

- Pressure drop changes likely due to be experimental error rather than fouling
- Effectiveness change possibly a leakage effect
- Leakage impact shown on next slide

Effect of thermal Cycling (1000 cycles) on Overall System Efficiency and Output Power (Considering recuperator pressure loss, effectiveness and leakage)







- Effect dominated by leakage
- 5% leak will reduce power by $>12.5\%$
- 5% leak will reduce system efficiency by $>4\%$
- Leakage knock on effects in engine life
 - Runs hotter affecting liner etc
 - Recuperator runs hotter – accelerated degradation



Life Comparison

Feature	Solar	Recup A	Recup B	Recup C	Recup D	Recup E	Recup F	Recup G
Recuperators Built	>500	<10	<10	<10	>10	>10	>100	Circa 1000
Test Life (Rig cycles)	300	1100	1000	Not yet tested	1900	Not yet tested	Not yet tested	1972
In Service Cycles – highest Individual	Circa 1000	NA	NA	NA	>1200	>1000	>3000	>1000
In Service Hours – highest individual	>7500	NA	NA	NA	NA	>1500	>8000	>8000
Fleet Hours	>200K	NA	NA	NA	NA	NK	>100K	>100K
Fleet Starts	>50000	NA	NA	NA	NA	NK	>10000	>30000



Integration Aspects

Feature	Solar	Recup A	Recup B	Recup C	Recup D	Recup E	Recup F	Recup G
Type	Box	Annular	Annular	Box	Annular	Annular	Box	Box
Ducting Included?	No	TBA	TBA	TBA	No	Yes	Yes	TBA
Mass – matrix + ducting	Ref	>	>	>	=	=	=	=
Sealing Issues	Ref	Worse	Worse	Same	Same	Better	Same	Better
Assembly time	Ref	Better (novel fastener)	Worse	Better	Same	Better	Same	Same
Field Replacement	Ref	Same	Same	Same	Same	Worse	Same	Same
Integration sensitivity to performance	Ref	Better	Better	Better	Same	Same	Same	Better



Integration Issue

- Performance and comments are based on configurations as supplied for testing purposes
- Interfaces will be optimised for engine productions
- Engine integration will be reviewed thoroughly in the next few months



Commercial Aspects

- Selection will also be related to
 - Cost of ownership (through life)
 - Supplier maturity
 - Capital investment required
 - Warranty terms



Conclusions & Summary

- There are more choices for recuperator now then there were 8 years ago
- Manufacturing developments have moved on, materials have not
- BPS are close to completing their recuperator evaluation program
- One will be selected to supersede the Solar unit for introduction in 2004 during Q3/2003
- So far 6 different units have been tested (in some cases more than one sample per supplier)
- Several are comparative to the Solar baseline performance
- Several exceed the Solar durability on the test rig
- At least two more manufacturers products to be tested before final selection is made
- When considering through life cost, effectiveness, pressure drop and leakage are crucial